Report of the NGST Mid–IR Camera/Spectrograph Sub–Committee

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Executive Summary

As directed by the NGST Project Scientist, we have attempted to review the science case and preliminary instrument concepts for the Next Generation Space Telescope with the goal of making recommendations regarding mid–infrared imaging and spectroscopy. We find that the programs enabled by a mid–infrared capability are crucial to successfully carrying out the science mission of NGST and strongly urge one of the three NGST instruments be devoted the mid–infrared. Furthermore, we believe there are no difficulties which make the inclusion of a mid–infrared capability technically or fiscally unfeasible for the NGST project. A variety of credible instrument concepts have been studied and all have advantages and disadvantages for carrying–out specific science programs. We have chosen not to advocate a particular instrument concept, but rather to articulate the *capabilities* required in order to complete the NGST core science:

• a two-channel system with short-wavelength (4.5-12 μm) and long- wavelength (12 to $>$ 28.3+ μm) imaging and low-resolution (R = 1-300) spectroscopic capability with matched $>$ 2'x2' FOV Nyquist sampled at 5 and 12 μm respectively.

• $R \geq 3000$ spectroscopic mode capable of achieving full spectral coverage from 4.5-28.3+ μm over a 10" $\times$ 10" FOV.

• pupil and/or focal plane coronagraphic mask options in the camera.

1. Introduction

The charge to the Mid–IR Camera/Spectrograph Sub–committee was to place questions posed to the ASWG regarding the ranking of instrument capabilities "...in the proper context and to make a preliminary recommendation to the ASWG which ranks and characterizes the generic instrument concepts". Further, we were "...to consider the needs of the NGST science program and particularly the DRM with regards to the capabilities of the ISIM study results". In order to carry–out these tasks, we met once in person at the NGST Science and Technology Exposition on September 16 in Hyannis, MA. Further we held four telecons: October 1, October 8, October 22, and October 29.

Members also contributed through electronic mail. A record of our meetings including agendas, inputs, questions for the technical panel review, and minutes can be found at: http://gould.as.arizona.edu/ngst/midir/.

Although we came to broad agreement in several areas we did not endeavor to come to complete consensus regarding which specific instrument concepts should be endorsed. This was in part due to the limited time and resources as our disposal. However, several members of the sub–committee felt that it was premature to overly restrict the range of acceptable instrument designs. Therefore we sought to define the *instrument capabilities* required in order to carry–out the science programs identified as central to the NGST science mission. We considered the top seven proposals as ranked by the ASWG as well as other DRM programs that required mid–infrared observations. We begin with a discussion of the scientific rational for a mid–infrared capability. We then discuss instrumentation issues including detector performance, instrument modes and concepts, and the observatory impact of the mid–IR. Finally, we summarize our conclusions.

2. Scientific Rational

2.1. Formation and Evolution of Galaxies

The MIR spectral region offers several unique opportunities to study the epoch of galaxy formation, $z > 2$. In addition to the many astrophysical processes with signatures in the MIR, such as PAH emission and molecular hydrogen lines, the well-studied and important optical and NIR features shift into the MIR at these epochs. Three in particular are noteworthy and lie in the 5–12 μm portion of the MIR for redshifts of $z = 2 - 20$:

1. The rest-frame 2 μm flux is the best diagnostic for determining the total mass in stars for systems whose mean stellar age is greater than 50-100 Myr. Hence, MIR-band imaging of high redshift galaxies is an important part of the high priority imaging surveys. The principle requirements are field of view (as large as feasible) and wavelength coverage (at least to the upturn in background due to sunshield scatter).

2. Measuring the internal stellar dispersions of established spheroids using the CO molecular bands at 2.3 μm rest. These are some of the strongest photospheric features in the integrated spectra of galaxies with ages greater than 50-100 Myr (Engelbracht et al. 1996). At z > 1, these bands are observed in the MIR to determine the concentration of total mass (luminous and dark) in early spheroids. To measure velocity dispersions in low luminosity galaxies $L < L_*$ (i.e. > 100 km s^{-1}) requires spectral resolution $R \sim 3000$ but only modest field as large, bright sources should be rare (~ 1 arcmin^{-1}) at redshifts z= 2-3.

3. Determining the star formation rate, reddening, and metalicity of star-forming galaxies at z = 7-20 as illustrated in Figure 1. See Kennicutt (1998) for a review of the physical diagnostics obtained from analysis of galaxy spectra. The strong emission lines of hydrogen, oxygen, and nitrogen can be observed in the MIR for this broad range of redshifts; a broader range than provided by the NIR since groundbased observations should accomplish much of this science for the redshift range of z = 1-3. While the number of potential sources is quite high at the faintest levels (similar to those in the NIR spectroscopic surveys) it is not clear the proposed MOS devices can provide sufficient background attenuation at the high spectral resolution required to reduce the impact of the zodiacal background ($R < 5000$). Hence the most important requirements are spectral resolution and low detector noise (0.2 e- s^{-1} per pixel equivalent dark current, comparable to the better SIRTF detectors). Improvements to the detector noise will directly affect the sensitivity of the MIR spectrographs.

2.2. Obscured Star Formation at High Red-shift

Attempts to determine the star-formation history of the Universe, such as CFRS reaching z $\sim$ 1, and the statistics of Lyman-limit galaxies at higher redshifts, have now been made (Lilly et al. 1996; Madau et al. 1996). The results imply that the star-formation rate was an order of magnitude greater at z $\sim$ 1 than in the local Universe, it peaked at z $\sim$ 1-1.5, and then declined to values comparable to those observed at the present day at z $\sim$ 4. However this conclusion, derived from rest-frame UV-optical data, may be misleading, because absorption by dust in distant galaxies undergoing massive star-formation may have distorted our picture of the evolution of the high-redshift universe in two ways. First, the star-formation rate in known high-redshift objects is under-estimated unless some correction for extinction is included in deriving the UV luminosity. Second, it is possible that a population of heavily dust-enshrouded high-redshift objects, predicted in some models of galaxy formation, have gone undetected in the optical/UV-selected samples (Puget et al. 1997; Smail et al. 1997).

The correction for extinction is controversial, while hints of a significant high-redshift population of IR-luminous galaxies are emerging. SCUBA, and in the near future SIRTF, will discover members of this population. Dust extinction decreases with wavelength, and is about 25 times less at 2.2 μm than at 140 nm. For z=3-5 near-IR, reddening independent, measures of morphology and star formation rate (e.g., Pα) can be measured from 5-15 μm. In this wavelength range NGST is exquisitely sensitive to 3.3 μm PAH emission, and can trace deeply extincted starformation to z=5. The mid-IR also exploits tracers which are

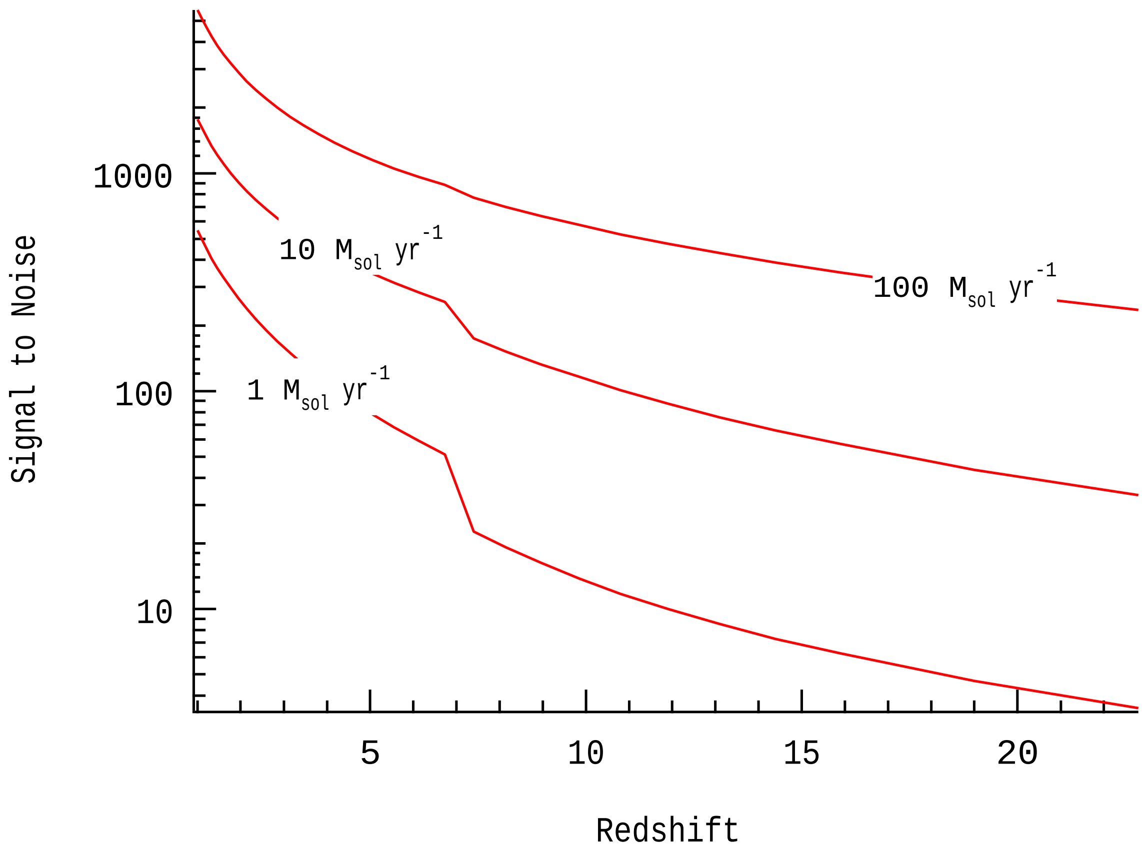

Fig. 1.— The signal to noise versus redshift for detecting H α emission from point-like, star–forming regions ($\Omega_{matter} = 0.3, H = 70, \Omega_{\lambda} = 0.7$). The break near z=7 is due to the increased dark current in Si:As BIB detectors and marks the transition of Hα into the MIR. At the highest redshifts, we require spectral resolutions of $R > 5000$ to reduce the zodiacal background below the assumed effective dark current, 0.2 e- s^{-1}. At such high resolutions, the lines will be resolved. Hence, the SNR values are optimistic at high redshifts and should probably be reduced by a factor of 2-3. In addition, the brightest star forming regions correspond to Arp 220-type circumnuclear starbursts and may be heavily reddened, even at Hα.

crucial to distinguish between star formation and AGN luminosity, including IR coronal lines (e.g., [SiVI], [SiVII], [SiIX], [SIX], and [CaVIII]), rotation-vibration emission of hot H_2, and emission from dust.

The primary objective of this program is to establish the luminosity function of distant, dusty star–forming galaxies. The mid-IR luminosity and the PAH dust feature, which is excited in photodissociation regions, are very strongly correlated with the luminosity of hot young stars (see Figure 2). Therefore, the luminosity function can be translated directly into the global star formation rate. Sufficient numbers of galaxies, including about 200 ultraluminous infrared galaxies at z < 3, will be detected to construct the luminosity function as a function of z to discriminate between density evolution, luminosity evolution, or a combination of the two. Since this survey volume includes the epoch where the co-moving number density of quasars is at a maximum, this luminosity function will be the principle tool for establishing an evolutionary link between ultraluminous IR galaxies and quasars (Sanders et al. 1996).

2.3. Physics of Star Formation: Protostars

Mid-infrared observations with NGST will be a very powerful tool providing insight into the physical processes occurring in the earliest, deeply embedded protostellar stage. During the first stages of collapse ($\tau < 10^5$ yr), protostars are still being assembled through accretion of material from circumstellar disks and envelopes. Mid-infrared continuum images at > 20 μm will uniquely probe the warm part of the accretion disk and the inner envelope, leading to constraints on the elusive mass infall rate. Medium resolution spectroscopy of solid-state features can probe the chemical composition of ices and silicates across the disk and infall envelope, and measure changes in properties due to grain growth and evolution (see Figure 3). Finally, low and medium resolution imaging in different spectral lines — in particular the H_2 pure rotational lines and the [S I] 25 μm line — provide insight into the physics of the accretion shock at the disk surface, as well as the interaction of the outflow with the inner envelope (Neufeld and Hollenbach, 1994). The high sensitivity and spatial resolution of NGST are essential for this project, since the youngest protostars have continuum fluxes < 1 mJy and sizes of at most a few arcsec in the mid–IR.

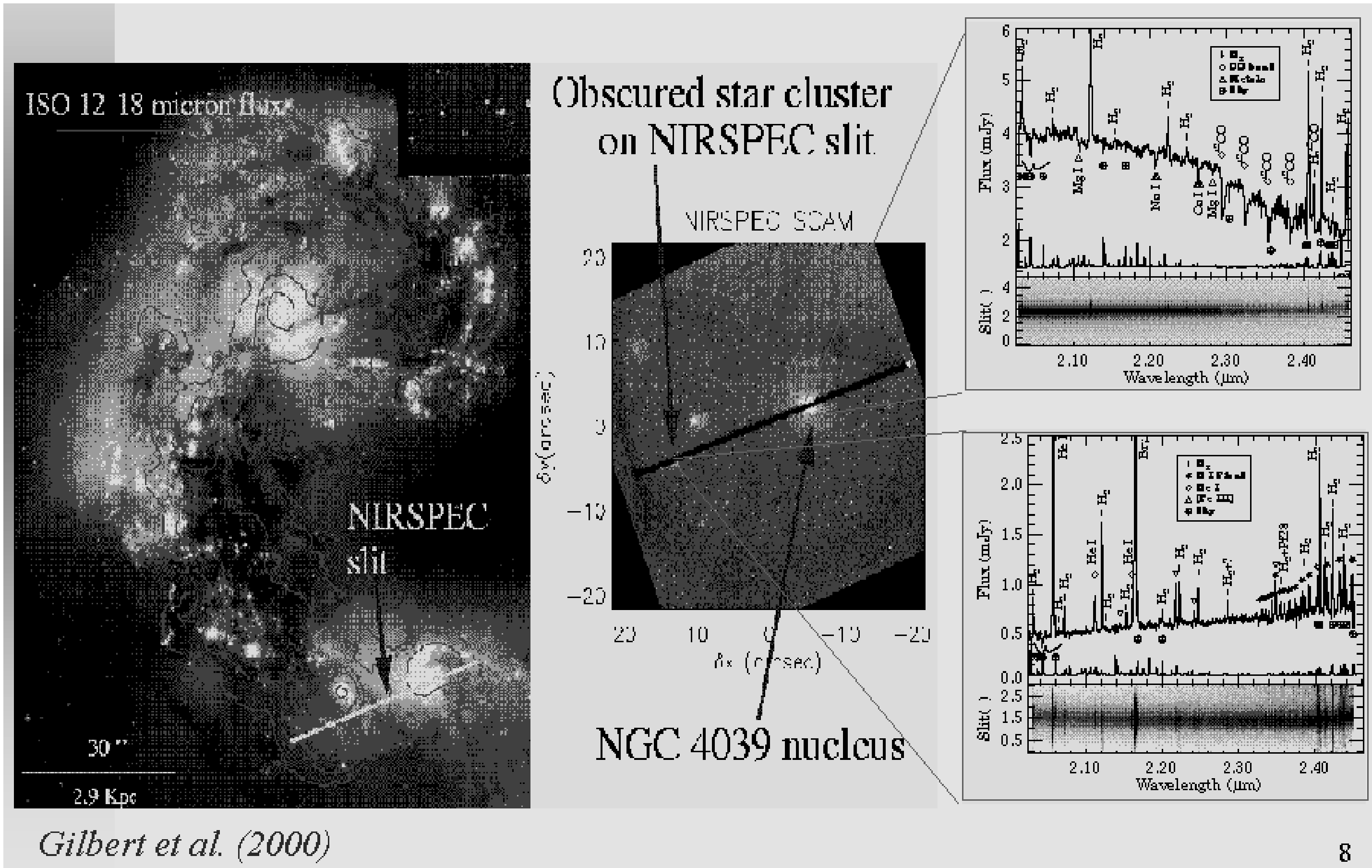

Fig. 2.— Obscured star–formation in the Antennae galaxy observed with the Hubble Space Telescope, ISO, and Keck. Contours represent ISO 10 μm fluxes super–posed on the HST visible light image. Near–IR slit spectroscopy with NIRSPEC at Keck reveals details concerning the stellar populations and nebular emission in the evolving star–burst (Gilbert et al. 2000).

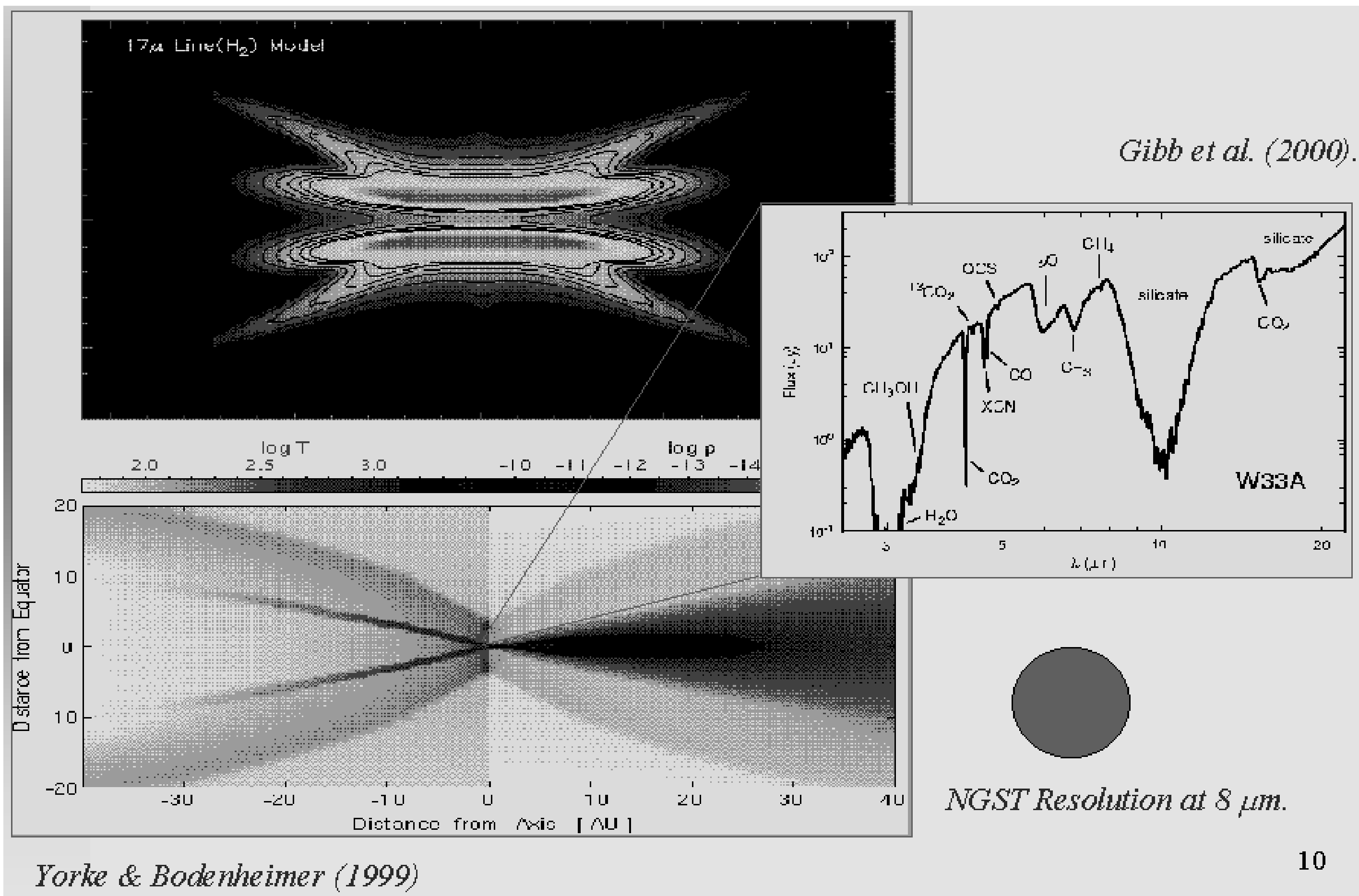

Fig. 3.— Mid–IR continuum images of a collapsing protostar from the models of Yorke and Bodenheimer (2000) compared to the diffraction–limit of NGST at 8 μm projected to a distance of 150 pc. Also shown is an ISO SWS spectra of a deeply embedded protostar from van Dishoeck et al. (1998). Indicated are prominant ice and dust features observed which provide insights into dust processing from the diffuse ISM to protostellar disks and envelopes.

2.4. Evolution of Circumstellar Disks

Over the past 15 years, tremendous progress has been made in understanding the structure and evolution of optically–thick dust disks commonly observed to surround pre–main sequence stars (Beckwith et al. 2000). However, establishing a direct relationship between these young star+disk systems and the origin of our own solar system remains elusive. In 2007, NGST will be in a unique position to attack two of the outstanding problems that will likely remain; the evolution of molecular gas and grain processing in circumstellar disks.

By conducting a medium resolution mid–IR spectroscopic survey for H_2 in disks surrounding young stars from 1–100 Myr one can determine when gas dissipates in the disks, constraining the epoch of giant planet formation (see Figure 4). Follow–up observations to search for trace molecular species in the warm inner disks detected will provide crucial inputs for models of nebular chemistry. Adding a high resolution (R = 30,000) mid–IR spectroscopic capability, would enable kinematic studies of the gas, allowing gas temperature and density to be mapped as a function of disk radius (Carr and Najita, 1997). Mid–IR imaging and moderate resolution spectroscopic surveys of remnant dust disks aged 1–300 Myr will provide powerful constraints concerning physical structure of the disks as well as the processing history of the dust. With direct images between 5–25 μm one can determine the density and temperature distribution of the dust in the remnant disk and discern the presence of inner holes (if present) in disks surrounding solar mass stars (Koerner et al. 1998). By obtaining *spatially–resolved* spectra from 10–25 μm along the major axis of the resolved disks, one can investigate the composition of the dust in these systems as traced by the solid state features populating the mid–infrared.

Such observations will help to answer three fundamental questions of disk evolution and planet formation; i) when does gas dissipate in circumstellar disks?; ii) do remnant dust disks surrounding solar mass stars exhibit similar inner holes to those inferred around early–type stars?; and iii) when and where does grain growth/processing occur in protoplanetary disks? A mid–infrared capability for NGST is crucial to learning when and where planets form in circumstellar disks surrounding young stars – a key goal of the NASA Origins program.

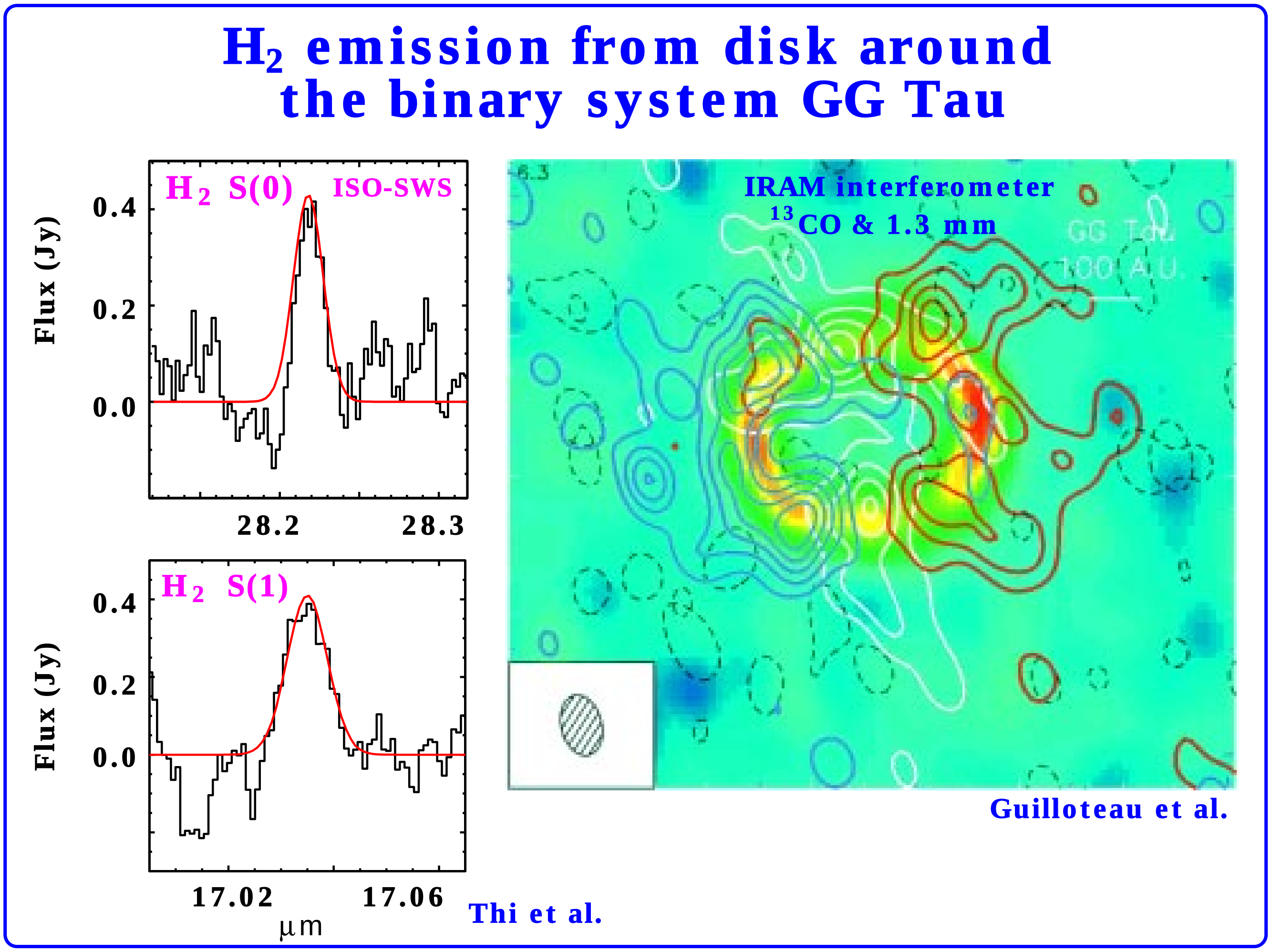

Fig. 4.— The first detection of cold (50–200 K) H_2 in a circumstellar disk surrounding a young star obtained with ISO (Thi et al. 1999). The grayscale image shows the mm continuum flux while the contours indicate the ^{13}CO emission. Dynamical interactions between the binary star system and the circumstellar disk have cleared a gap in the dust responsible for the mid–infrared continuum enabling detection of the emission–line gas.

3. Instrumentation Issues

3.1. Detector Performance

State-of-the-art MIR detectors already perform very well, but further development is needed to achieve the NGST science goals. Although limited to 256 x 256 pixel formats, the SIRTF Infrared Array Camera (IRAC) Si:As detectors have demonstrated high quantum efficiency and encouragingly low dark currents. The NGST project is already working on extending the (MIR) detector device format to 1024 x 1024 pixels. Devices of this size should be adequate for use in the NGST MIR instrument, either individually or in small (2 x 2) mosaics. Thus it would be most cost effective to focus future MIR detector development on the priorities of 1) reducing total noise; and 2) extending the cutoff wavelength so that the 28.2 μm H_2 line is detected with adequate sensitivity. The NGST Detector Requirements Panel has also recommended strong support for these MIR detector developments (McCreight et al. 1999).

State-of-the-art SIRTF Si:As detectors have read-noise of approximately 8 e- (multiply sampled) and dark currents as low as 0.1 e- s^{-1}. This performance is adequate for background-limited performance on NGST for imaging and low-resolution spectroscopy ($R < 100$) at wavelengths $\geq$ 6 μm. However, the high priority DRM programs with MIR components call for R = 300 - 3000 observations, so the present detectors would seriously impact the quality of their data. Improving read-noise to 3 e- and dark current to below 0.01 e- s^{-1} would allow NGST to be background-limited at R$\leq$ 1000 at wavelengths as short as 6 μm. This performance would be adequate for these programs.

The development cost of improving MIR detector performance is quite modest (a few million dollars) compared to the cost of NGST instruments and operations (several tens of millions per year). Improving detectors directly reduces the spectroscopic observing time required to achieve scientific goals, so early detector development is very cost effective. For example, one year of spectroscopic observations with current SIRTF detectors could be done in only 6 weeks if their noise performance was improved to the values above (disregarding format differences).

Even with further development, only detectors with modest well capacities (a few $\times 10^5$ e-) will achieve these stringent noise performance goals. Detectors with larger well capacities will be required for long-wavelength ($\lambda \sim 28\mu$m) broad-band imaging, a key component of several DRM programs. This is because the total background is expected to be on the order of $3\times10^5 \gamma s^{-1}$ incident on the detectors when Nyquist sampled, and the detectors are expected to require over 1 second per readout (in order to minimize power dissipation and electronics complexity). Fortunately much worse noise performance can be tolerated in such high background applications.

The most straightforward and low-risk approach to achieve both low noise performance and large well capacities where needed is to provide 2 separate MIR channels. This would provide the greatest scientific utility if the specific implementation (i.e. separate modules or else different camera trains within the same instrument) also provided 2 different plate scales so that near-Nyquist sampling is provided over a broad range of MIR wavelengths. The longer wavelength channel would have detectors with larger well capacities and increased doping (and increased absorbing layer thicknesses). Increasing the doping levels/thicknesses of Si:As detectors increases their long wavelength response cutoff, so this may provide a low-risk method of ensuring that the 28.2 μm H_2 line can be observed with adequate sensitivity. One way to divide the channels is to have one cover 5 - 12 μm and the other cover 12 - 29 μm, 1.2 octaves each. It would be most efficient to equip each of these channels with both imaging and spectrographic modes.

3.2. Instrument Modes and Concepts

The instrument capabilities required to carry–out the programs outlined in the DRM are summarized in Table I. In discussing the advantages and disadvantages of various instrument concepts we separated consideration of imaging and low resolution spectrophotometry (R = 1-300) from moderate and high resolution spectroscopy (R > 1000). The instrument concept designs considered are summarized in Appendix A. Our general recommendations are as follows, with particular emphasis on the areas of general agreement.

Concerning the camera/low resolution spectrograph we agreed that a two–channel system (short wavelength and long wavelength) was highly desirable. Not only would this enable proper sampling of the images over a wider wavelength range, but also detector performance could be optimized with regard to coatings etc. In order to preserve FOV while maintaining the ability to recover spatial information through dithering strategies, we recommend that the images be sampled within a factor of $\times 2$ the diffraction limit of the shortest observable wavelength. It was further agreed that the long wavelength channel should extend to ≥ 28.3 μm with the goal of extension to 35 μm if practical. Because of the minimal impact on the instrument, we advocate that coronagraphic masks (implemented in the pupil and/or focal plane) be included in the baseline camera design with the highest priority being the short wavelength channel. This would enable high contrast imaging, such as studying host galaxies of quasars/AGN as well as the search for Jupiter mass planets around nearby stars.

In order to carry–out the top seven DRM programs, it was estimated that between 10–30 filters broad– and narrow–band filters would be required. There was not unanimous agreement regarding the benefits of the IFTS for multi–spectral imaging versus the loss in point–source sensitivity in a single spectral element. A fraction of the sub–committee expressed the opinion that a staring camera+filters would best carry–out the extragalactic broad–band imaging surveys, while the IFTS would be superior for the obscured star formation at high redshift program. Multi–spectral imaging at R=100 over a 2' x 2' FOV would be a powerful way to carry–out the imaging portion of the protostars program. However, it was unclear whether the staring camera+filters or IFTS would be preferable for the circumstellar disks programs. In both the protostars and disks programs, the imaging observations are precusors to moderate resolution spectroscopy discussed below. Some members felt that a relative cost and risk assessment was needed in order to choose between the IFTS and a simple staring camera+filters.

With regard to spectroscopy, there was general agreement that the MINIMUM ACCEPTABLE mid-IR instrument should contain spectroscopic capability of $R > 1500$. However, some DRM programs call for R=3000 in order to answer the scientific questions posed. In terms of generic attributes of a moderate resolution imaging spectrograph, it was felt that spectral coverage was most important, followed by spectral resolution, and finally field of view. We felt strongly that any mid–IR spectrograph should have the CAPABILITY of obtaining a full spectrum over the operating wavelength of the detector at R=3000 across a 10" × 10" FOV. How exactly to divide an individual exposure between spectral coverage and field of view was a matter of debate. Specific implementations considered were the integral field unit, longslit spectrograph, and cross–dispersed echelle. Because of the high background and low source density at this spectral resolution, it was concluded that the IFTS was not competitive for these programs. For the extragalactic CO spectroscopy, a significant fraction of the sub–committee felt that the cross–dispersed echelle was the best option. For the protostar and circumstellar disks programs, there was a slight preference for the IFU over the echelle. One potential compromise could be a cross–dispersed format with half the number of orders allowable, permitting more efficient focal plane use (with smaller gaps between orders). The smaller spectral range covered (e.g. 3 μm versus 6 μm) would enable mapping of a larger spatial area (perhaps a folded image slice) of order 2.5" × 2.5" FOV at R=3000 on a single 1024 x 1024 array. To summarize, it was felt that some capability of imaging spectroscopy at R=3000 was crucial and that there are various paths to achieving this. Additional technical studies are required in order to effect quantitative comparisons between a longslit spectrograph and an IFU.

3.3. Observatory Impact

A major concern in adding a mid-IR instrument to NGST is the impact on the design of the observatory in optimizing this capability. The two dominant factors in determining background–limited performance are; i) scattered thermal emission from the sun shield; and ii) thermal emission from the ISIM environment. The intensity of the scattered emission from the sun shield depends primarily on the cleanliness of the mirrors and the temperature of the sun shield. The cleanliness of the mirrors must be controlled appropriately to reduce the scattered light not only for the mid-IR, but also for the entire spectral range of the NGST. With reasonable limits on mirror contamination, the temperature of the sun shield must be lower than $\sim$ 90K in order to keep the scattered thermal emission smaller than the natural background (zodiacal emission) for >12 μm. A mirror of T < 40K will not contribute to the background radiation more than the natural background for >20 μm. Such mirror temperatures are achievable with the mid-IR compatible OTA design outlined by Bely et al. (1998).

The mid-IR instruments must have the enclosure of the temperature lower than 18K to reject the thermal emission from the ISIM (40K). The thermal emission from the enclosure acts like dark current and the background level is very sensitive to the enclosure temperature (Serabyn et al. 1999). The enclosure temperature should further be reduced if the spectral range is extended to > 28 μm. The mid-IR detectors must be kept below 10K, depending on the detector type (see McCreight et al. 1999). Preliminary thermal designs indicate that the emissivity of the enclosure is required to be less than 4-5% in order to reduce the radiation heat load from the ISIM (40K) to a level compatible with that through the mechanical supports. There are multiple cooling systems available which are capable of satisfying these temperature requirements (Ennico et al. 1998; Wright et al. 1998). Further detailed design studies of the mid-IR instruments alternatives, including the cooling system, are needed to accurately estimate the thermal background contribution from the ISIM and the enclosure.

4. Conclusions

Because of the tremendous advantage of NGST over ground-based mid-IR capabilities, and the enhanced spatial resolution and sensitivity over ISO and SIRTF, even the most simple instrument would enable fundamentally new science in the mid-IR. However, the instrumentation recommended here would represent a sensible investment commensurate with that required to build the NGST. We outline; i) the capabilities required in order to conduct the top seven science programs ranked by the ASWG; ii) the desired capabilities needed to undertake the additional compelling science programs listed in Table I; and iii) the capabilities necessary for a mid–infrared instrument to take minimum advantage of the unique platform offered by the NGST.

REQUIRED

• two-channel system with short-wavelength (4.5-12 μm) and long- wavelength (12 to > 28.3+ μm) imaging and low-resolution (R = 1-300) spectroscopic capability with matched > 2'x2' FOV Nyquist sampled at 5 and 12 μm respectively.

• $R \geq 3000$ spectroscopic mode capable of achieving full spectral coverage from 4.5-28.3+ μm over a 10" × 10" FOV.

• pupil and/or focal plane coronagraphic mask options in the camera.

DESIRED

• imaging and spectroscopic capability (R > 1500) extended to ≥ 35 μm.

• high resolution (R ≥ 30,000) spectroscopy from 4.5 to > 8 μm.

MINIMUM CAPABILITY

• a 1k × 1k 5 to > 28 μm imager with > 1' × 1' FOV.

• between 10-30 spectral elements/filters at $1 < R < 100$.

• capability for R > 1500 spectroscopy.

5. Appendix A. Summary of the ISIM Concepts Under Study

Ennico et al. report entitled *An Integrated Science Instrument Module for the Next Generation Space Telescope* includes description of a mid–IR capability from 5–27 μm as well as a "long wavelength" channel that would operate from 20–34 μm. The mid–IR module would have options for broad– and narrow–band imaging utilzing a single 1k × 1k Si:As detector sampled at 0.103" pixel^{-1} for a 1.8' × 1.8' FOV, as well as long–slit grism spectroscopy from R = 100–1000. The report also describes a cross–dispersed mid–IR echellete module which would provide R = 3000 over seven orders along a 9" slit. The long–wavelength channel would utilize a 512 × 512 Si:P detector sampled at 0.387" pixel^{-1} for a 3' × 3' FOV along with grism slit spectroscopy from R= 500–1000. A long–wavelength echellete mode with R=3000 is also described.

The Graham et al. report entitled *An Integral Field Infrared Spectrometer for the Next Generation Space Telescope* describes a four–port design for an imaging Fourier transform spectrometer (IFTS) with both near– and mid–infrared channels. The IFTS concept would provide R=1-300 spectroscopy in the standard modei over the full field of view, with higher resolving powers in dispersed mode up to a maximum of $R = 3000$ in the mid–IR channel. This instrument would utilize a 2×2 mosaic of Si:As detectors operating over the wavelength range from 3–28 μm with a 1024 array format. The field of view would be 2.64' $\times$ 2.64' with a pixel scale of 0.0772" pixel^{-1}.

The Serabyn et al. report entitled *A Mid–Infrared Camera for the Next Generation Space Telescope* reviews several possibilities for a combination camera+spectrograph. This study advocates a two–channel system; one optimized for 5-15 μm made up of a 2×2 detector mosaic of 1024x pixel arrays sampled at 0.07" pixel^{-1} for a 2.4' $\times$ 2.4' FOV and another 1k $\times$ 1k array optimized from 15–30 μm and sampled at 0.14" pixel^{-1} for a matched FOV. There would be two grating spectrograph modules with R=1000 for use in both channels. Options include tapered slits, image slicers, and a cross–dispersed mode. A variety of grating selectors and flip mirrors are called for in order to provide maximum flexibility with a small number of focal plane arrays. Several descope options are presented.

The Wright et al. report entitled *MIRCAM & MIRIFS: Mid–IR Instrumentation for the Next Generation Space Telescope* describes a mid–infrared camera and spectrograph which relies on an integral field unit to provide imaging spectroscopy. The camera design is similar to that outlined in the Serabyn et al. report; a two–channel system operating between 5–10 μm and 10–28 μm providing a matched 2.5' $\times$ 2.5' FOV. The short–wavelength (SW) channel would require a 2×2 array of 1k detectors and a single long–wavelength (LW) array sampled at 0.065" and 0.13" pixel^{-1} respectively. The IFU module would also have separate SW and LW channels with a resolving power of $R \sim 1000$. The SW channel would provide a 5.4" $\times$ 8.5" FOV sampled at 0.15" while the LW channel would spectrally image a field of 6" $\times$ 10" sampled at 0.3" pixel^{-1}.

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Table 1. DRM Programs Requiring Mid–IR Capability for NGST

ID	Program	Mode	λ	R	SNR	F(AB)	Diameter	n(o)	N(total)
18	Gamma-Ray Burst	MIR-ACCU	10.2	3	10	26	0.2	0	100
18	Gamma-Ray Burst	MIR-ACCU	10.2	3	10	26	0.2	0	100
18	Gamma-Ray Burst	MIR-ACCU	10.2	3	10	26	0.2	0	100
08	Physical KBO	MIR-ACCU	10	3	10	26	0	0.04	100
08	Physical KBO	MIR-ACCU	20	3	10	23.7	0	0.04	100
08	Physical KBO	MIR-ACCU	30	3	10	23.7	0	0.04	100
20	Circumstellar disk	MIR-SPEC	4.5-28	3000	100	13	4	1[a]	120
20	Circumstellar disk	MIR-SPEC	4.5-17	30000	100	13	4	1[a]	80
20	Circumstellar disk	MIR-SPEC	5-35	1500	30	14.8	4	1[a]	80
12	Star Formation	MIR-ACCU	7	5	10	24	10	1[a]	120
12	Star Formation	MIR-ACCU	13	5	10	24	10	1[a]	120
12	Star Formation	MIR-ACCU	25	5	10	22	10	1[a]	120
12	Star Formation	MIR-ACCU	35	5	10	22	10	1[a]	120
12	Star Formation	MIR-SPEC	4.5-35	100	10	18	180	1[a]	120
12	Star Formation	MIR-SPEC	4.5-28	3000	50	16	10	1[a]	120
13	Sub-stellar Objects	MIR-ACCU	10.2	5	5	28	0	100	10
14	Ex-gal Deep	MIR-ACCU	10.2	3	5	30	0.5	1000	1000
14	Ex-gal Wide Field	MIR-ACCU	10.2	3	5	30	0.5	2500	1000
15	Kinematic CO	MIR-SPEC	5-10	5000	5	22	0.5	0	20
16	Ex-gal Cluster	MIR-SPEC	5-10	5000	10	22	0.5	0	7
09	Obscured SF	MIR-ACCU	8	3	5	27.5	0.5	0.04	16
09	Obscured SF	MIR-ACCU	16	3	5	27.5	0.5	0.04	16
09	Obscured SF	MIR-ACCU	24	3	5	23.8	0.5	0.04	16
09	Obscured SF	MIR-ACCU	36	3	5	23.8	0.5	0.04	16
09	Obscured SF	MIR-ACCU	8	3	5	26.5	0.5	0.04	16
09	Obscured SF	MIR-ACCU	16	3	5	26.5	0.5	0.04	16
09	Obscured SF	MIR-ACCU	24	3	5	22.8	0.5	0.04	16
09	Obscured SF	MIR-ACCU	36	3	5	22.8	0.5	0.04	16
09	Obscured SF	MIR-SPEC	5-20	300	10	23	0.5	0	50

[a]Some parts of these programs could be conducted in clustered regions with source densities of 10–100 amin^{-2}.